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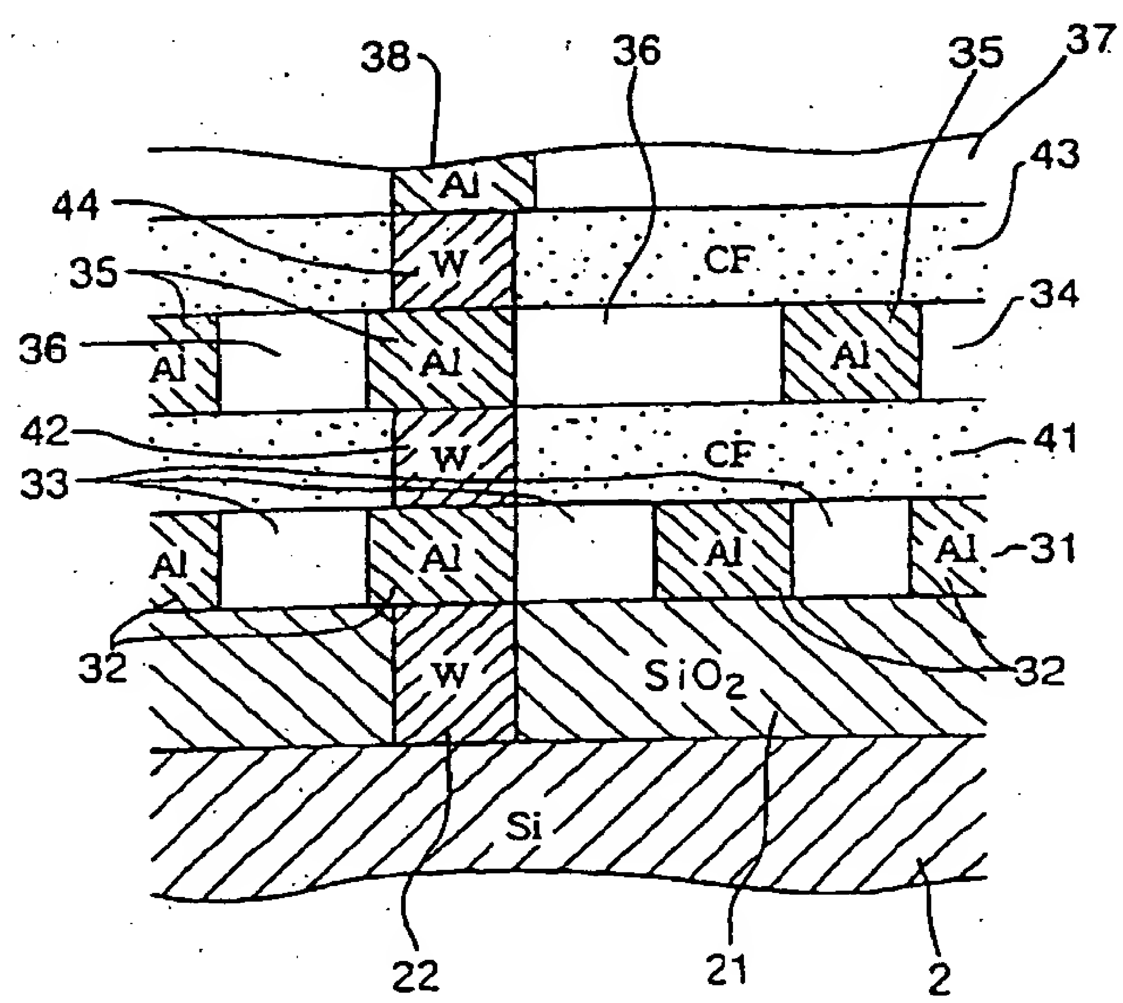
(54) SEMICONDUCTOR DEVICE AND ITS PRODUCTION METHOD

(57) On a first interlayer insulating film 41, a second wiring layer 34 comprising a plurality of wirings 35 with concave portions between adjacent ones of the wirings 35, is superposed. A second interlayer is insulting film 43 is superposed on the second wiring layer 34. The second interlayer insulating film 43 layer 34 is made of film producing material, such as CF film, that is unlikely to serve as filling due to its intrinsic property. Gasses that are used to produce the film producing material unlikely to be filling include C_6F_6 gas, for example, and ionizing the gas into plasma allows the CF film to be formed on the wiring layer 34 while inhibiting the CF film from filling the concave portions 30. In this way, air gaps 36 are defined in shapes similar to those of the concave portions 30 between the wirings 35. The semiconductor device manufactured in such a manner can avoid reducing its mechanical strength while capacities between the wirings are decreased.



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EP 1 152 463 A1

which comprises a plurality of wirings and which has concave portions formed between adjacent ones of the wirings, and forming an insulating film of film producing material on the wiring layer, wherein the step of forming the insulating film includes forming the insulating film on the wiring layer while inhibiting the film material from filling the concave portions between the adjacent wirings, so as to create depleted regions within the concave portions.

BRIEF DESCRIPTION OF DRAWINGS

[0011]

Fig. 1 is a sectional view showing part of an exemplary semiconductor device according to the present invention;
Fig. 2 is a diagram illustrating steps in an exemplary method of manufacturing a semiconductor device according to the present invention;
Fig. 3 is a cross-sectional view showing an exemplary apparatus using plasma in manufacturing the semiconductor device according to the present invention;
Fig. 4 is a diagram illustrating the steps in relation with features of the present invention;
Fig. 5 is a diagram illustrating steps of an exemplary process of forming a coating film when such a coating film is applied to the semiconductor device according to the present invention;
Fig. 6 is a diagram illustrating the steps in relation with features of the present invention;
Fig. 7 is a diagram illustrating steps of a method of manufacturing an alternative semiconductor device according to the present invention;
Fig. 8 is a diagram illustrating results of a test performed to observe effects of the present invention;
Fig. 9 is a diagram illustrating results of a test performed to observe effects of the present invention;
Fig. 10 is a sectional view showing part of a semiconductor device employed for explaining the diagram in Fig. 9;
Fig. 11 is a diagram illustrating an exemplary method of manufacturing a prior art semiconductor device;
Fig. 12 is a sectional view showing an example of air gaps formed in the prior art semiconductor device; and
Fig. 13 is a sectional view showing another example of the air gaps formed in the prior art semiconductor device.

BEST MODE FOR CARRYING OUT THE INVENTION

[0012] A preferred embodiment of a semiconductor device of the present invention will be described with reference to Fig. 1. Fig. 1 is a sectional view showing part of the semiconductor device that includes a silicon (Si) substrate 2, an insulating film 21 formed of material such as SiO_2 film, and a contact plug 22 formed in the insulating film 21 and filled with substance such as tungsten (W). A first wiring layer 31 is created on an upper surface of the insulating film 21, and the wiring layer 31 is provided with wirings 32 of aluminum (Al) and depleted regions 33 referred to as air gaps which are defined within concave portions between adjacent ones of the wirings 32.

[0013] The first wiring layer 31 as stated above, has its upper surface coated with a first interlayer insulating film 41 formed of material, such as CF film. The CF film is unlikely to serve as filling due to its intrinsic property, and the interlayer insulating film 41 is provided with plugs 42 filled with tungsten (W) to connect between the wirings 32 in the first wiring layer 31 and wirings 35 in a second wiring layer 34 which will be explained below.

[0014] The first interlayer insulating film 41 has its upper surface coated with the second wiring layer 34, and the wiring layer 34 has the wirings 35 formed of substance such as aluminum (Al) similar to the first wiring layer while having air gaps (depleted regions) 36 defined between adjacent ones of the wirings 35. The second wiring layer 34 has its upper surface superposed with a second interlayer insulating film 43 formed of material, such as CF film, that is unlikely to serve as filling due to its intrinsic property. The interlayer insulating film 43 is provided with plugs 44 filled with tungsten (W) to connect with wirings 38 in a third wiring layer 37 formed on an upper surface of the interlayer insulating film 43.

[0015] The interlayer insulating films will now be described in details. In general, interlayer insulating films include SiO_2 film, which is approximately 4 in its dielectric constant, and efforts have been made to obtain materials having smaller dielectric constants. Such materials include SIOF film having a dielectric constant of 3.5, and fluorinated carbon film (CF film) as mentioned above, which has a further smaller dielectric constant, may be used for such applications.

[0016] The CF film is made of material containing C and F, and a mixing rate of C to F can be optionally determined. For instance, the CF film may be made of mixture containing 65% of C and 35 % of F.

[0017] As for an exemplary method of manufacturing the semiconductor device as mentioned above, a mode will be described where the second wiring layer 34 and the second interlayer insulating film 43 are formed over the first interlayer insulating film 41, with reference to Figs. 2 to 4. First, the first wiring layer 31 is formed on the upper surface of the first interlayer insulating film 41. In this situation, as shown in Fig. 2(a), a titanium (Ti) layer 51 of 300 angstrom in thickness and a titanium nitride (TiN) layer 52 of 500 angstrom in thickness are successively formed one after another on the upper surface of the first interlayer insulating film 41. Thereafter, an aluminum (Al) layer 3 of 8000 angstrom in thickness is formed on an upper surface of the TiN layer 52. In the drawings, for the purpose of convenience, the Ti layer

concave portions 30.

[0027] At this point, keeping the radio frequency power supply 72 deactivated, i.e., withholding bias power can prevent plasma ions from being attracted into the wafer W during film development, thereby resulting in the CF film being more unlikely to serve as filling. Without filling the concave portions 30 in this way, the CF film 43 of 8000 angstrom in thickness is created on the upper surface of the TiN layer 54, and consequently, the air gaps (depleted regions) 36 are defined between the Al wirings 35 (see Figs. 2(d) and 4(c)). Subsequently, the second interlayer insulating film 43 is etched in predetermined patterns to form the plugs 44 configured of grooves filled with the tungsten (W) film.

[0028] The method of the present invention has made itself noteworthy in that gasses such as C_6F_6 gas are used to produce films that are unlikely to serve as filling due to their intrinsic properties. In this method, the wiring layer 34 is prepared in advance, with the concave portions 30 being defined between adjacent ones of the Al wirings 35, and then, the C_6F_6 gas is used to produce the CF film which is unlikely to be filling and which serves as an interlayer insulating film, overlying the wiring layer 34. Therefore, as stated above, the CF film is created, with the concave portions 30 kept almost completely unfilled with it. This allows the air gaps 36 to be easily created between the adjacent Al wirings 35, and moreover, allows the air gaps 36 to be defined in shapes similar to those of the concave portions 30 along the contours of them.

[0029] In other words, selecting the requirements of producing the CF film permits the CF film to be created without deposition on the bottoms or side-walls of the concave portions 30 but with deposition along the upper surface of the wirings while the film is closing the upper openings of the concave portions 30, and thus, the air gaps 36 between the wirings can be closely similar in shapes to the concave portions 30 along the contours of them.

[0030] The semiconductor device manufactured in the method according to the present invention has regions left depleted (empty) between the adjacent Al wirings. Since the regions are in vacuum state, namely, in conditions almost meeting the process requirements upon film development so as to have a dielectric constant of approximately 1, capacities between the wirings are small, which is suitable for miniaturization of the semiconductor devices. The air gap 36 defined between the wirings are in shapes almost similar to those of the concave portions 30 along the contours of them. Since the air gaps would not extend higher than the wirings, there is no risk of sections above the concave portions being reduced in mechanical strength, nor is there risk of the sections' cracking to give damage against the device.

[0031] In the foregoing mode of the embodiment, although the CF film is created under the conditions that bias power is not applied to make the shapes of the air gaps 36 that are almost similar to those of the concave portions 30 along the contours of them. However, the same results can be assuredly obtained by applying voltage lower than the normal bias power.

[0032] As has been described, as to the gasses used to produce the CF film which serves as the first and second interlayer insulating films and which is unlikely to be filling due to its property, gasses of compounds containing carbon (C) and fluorine (F) may be used, including C_6F_5H (pentafluorobenzene) gas, $C_6H_5CF_3$ (parachlorotoluene) gas, C_4F_8 gas, C_5F_8 gas, C_6F_{10} gas, and so forth, as well as the above-mentioned C_6F_6 (hexafluorobenzene) gas, and especially, compound gasses, such as C_6F_6 gas, C_6F_5H gas, $C_6H_5CF_3$ gas, which contain C and F and have benzene rings, are preferably used.

[0033] According to the present invention, the insulating film which is formed on the wiring layer with air gaps is not limited to an example of the CF film, but any insulating film may be used if it is made of materials that are unlikely to fill the concave portions between the wirings due to their intrinsic properties. Such insulating films include SiLK film (Registered Trademark by Daw Chemical), HSQ (Hydrogen Silsesquioxane) film, MSQ (Methyl Silsesquioxane) film, and other coating films having a low fluidity and a low dielectric constant.

[0034] An alternative mode of the above-mentioned embodiment will now be described in the context of using the coating film, especially, of SiLK film as the first and second interlayer insulating films. As shown in Fig. 5(a), while the wafer W is retained by a retainer 81 that is rotatable in a horizontal direction, coating material 82 containing SiLK film material and solvent for the film material is supplied to the surface of the wafer W, and then the wafer W is rotated by the retainer 81 in the horizontal direction, as shown in Fig. 5(b), to diffuse the coating material 82 throughout the surface of the wafer W.

[0035] Next, the wafer W is transferred to a baking apparatus having a cabinet 83 and a heating plate 83a therein, and after resting on the heating plate 83a, the wafer W is baked, for example, at 140 °C for a predetermined period of time until the solvent is vaporized and eliminated. After that, the wafer W is transferred to a heater having a cabinet 84 and a heating plate 84a therein. After resting on the heating plate 84a, the wafer W is cured, for example, at 400 °C for a predetermined period of time until the coating 82 is polymerized and cured, and thus, SiLK film 8 is created. Also, the curing procedure may be carried out in a furnace.

[0036] As can be seen, the SiLK film 8 is created by coating the wafer W with the coating material 82, and selecting coating requirements, such as increasing surface tension of the solvent, and/or, rotating the wafer W at higher velocity, permits the coating material 82 to diffuse in such a manner as closing openings of the concave portions 30 between the wirings 35, as shown in Fig. 6(a). As a result, the wafer W can be coated with the SILK film 8 with the concave portions 30 being hardly filled with the coating material (see Fig. 6(b)). Thus,

sccm, respectively. Under the microwave power of 2.3 kW and the bias power of 2.0 kW, the film producing gasses were ionized into plasma to create the SiO_2 film up to 8000 angstrom in thickness over the upper surface of the wiring layer while filling the concave portions between the wirings without creating the air gaps.

[Comparison 2]

[0046] C_6F_6 gas was used to produce films, and, in the above-stated plasma processing apparatus, the plasma gasses such as Ar gas was introduced at a flow rate of 150 sccm while the film producing gasses such as C_6F_6 gas and CF_4 gas were introduced at flow rates of 40 sccm and of 20 sccm, respectively. Under the microwave power of 1.0 kW and the bias power of 2.5 kW, the film producing gasses were ionized into plasma to create the CF film up to 8000 angstrom in thickness over the upper surface of the wiring layer while filling the concave portions between the wirings without creating the air gaps.

[Comparison 3]

[0047] $C_6F_5CF_3$ gas was used to produce films, and, in the above-stated plasma processing apparatus, the plasma gasses such as Ar gas was introduced at a flow rate of 150 sccm while the film producing gasses such as $C_6F_5CF_3$ gas and CF_4 gas were introduced at flow rates of 40 sccm and of 20 sccm, respectively. Under the microwave power of 1.0 kW and the bias power of 2.5 kW, the film producing gasses were ionized into plasma to create the CF film up to 8000 angstrom in thickness over the upper surface of the wiring layer while filling the concave portions between the wirings without creating the air gaps.

[Comparison 4]

[0048] C_6F_5H gas was used to produce films, and, in the above-stated plasma processing apparatus, the plasma gasses such as Ar gas was introduced at a flow rate of 150 sccm while the film producing gasses such as C_6F_5H gas and CF_4 gas were introduced at flow rates of 40 sccm and of 20 sccm, respectively. Under the microwave power of 1.0 kW and the bias power of 2.5 kW, the film producing gasses were ionized into plasma to create the CF film up to 8000 angstrom in thickness over the upper surface of the wiring layer while filling the concave portions between the wirings without creating the air gaps.

[0049] The results are shown in Fig. 8 where the dielectric constants between the wirings are designated as follows; the dielectric constant in the condition that the SiO_2 film is embedded between the wirings is denoted as $\varepsilon\ SiO_2$ while a relative dielectric property between wirings in the assumption that the dielectric constant is ε in each case is $\varepsilon/\varepsilon\ SiO_2$. From the results, it was observed that, using the CF film as the interlayer insulating film as in the Embodiments 1 to 3 and the Comparisons 2 to 4, the dielectric property $\varepsilon/\varepsilon\ SiO_2$ was lower in contrast to a case where the SiO_2 film was used to serve as the interlayer insulating film as in the Comparison 1, and that, defining the air gaps between the wirings as in the Embodiments 1 to 3, the dielectric property $\varepsilon/\varepsilon\ SiO_2$ was significantly lower in contrast to a case where the interlayer insulating film was embedded between the wirings.

[0050] At the same time, it was also observed in the Embodiments 1 to 3 and the Comparisons 2 to 4 that even if the same film producing gasses were used, change in the film developing conditions allowed the CF film to alter an amount of deposition in the concave portions between the wirings so as to control the procedure to make it an option if the air gaps were to be formed or not to be.

[0051] Similarly, SiLK film, HSQ film, and MSQ film were used for carrying out the similar experiments, and it was observed that the dielectric property between wirings $\varepsilon/\varepsilon\ SiO_2$ was approximately 0.3 in any case to form the air gaps while it was approximately 0.75 in any case to fill the gaps between the wirings with the interlayer insulating film, and it is also observed that creating the air gaps caused the dielectric property between wirings $\varepsilon/\varepsilon\ SiO_2$ to be reduced.

[0052] Additionally, in order to determine how the change in the types and film development conditions of the interlayer insulating film could affect shapes of the air gaps, the wiring layer provided with the Al wirings of 8000 angstrom in height and 6000 angstrom in width at intervals of 4000 angstrom between the adjacent wirings was further superposed with varied types of the interlayer insulating films of 6000 angstrom in thickness under varied film developing conditions so as to observe the development of the air gaps between the wirings. The conditions of the film development are defined as follows.

[Example 4]

[0053] C_6F_6 gas was used to produce films, and, in the above-stated plasma processing apparatus, the plasma gasses such as Ar gas and C_6F_6 gas were introduced at flow rates of 90 sccm and of 40 sccm, respectively. Under the microwave power of 2.0 kW and the bias power of 0 kW, the C_6F_6 gas was ionized into plasma to create the CF film up to 6000 angstrom in thickness over the upper surface of the wiring layer.

[Example 5]

[0054] C_6F_6 gas was used to produce films, and, in the above-stated plasma processing apparatus, the plasma gasses such as Ar gas and C_6F_6 gas were introduced, at flow rates of 90 sccm and of 40 sccm respectively. Under the microwave power of 2.0 kW and

produce plasma, may be used.

[0066] As has been described, according to the present invention, a semiconductor device is provided, with depleted regions being defined between wirings to reduce capacities therebetween, wherein the depleted regions can be created in shapes similar to those of concave portions between the wirings along the contours of them, so that the semiconductor device can maintain mechanical strength at the portions associated with the depleted regions while reducing capacities between wirings. Furthermore, the semiconductor device can be manufactured in a simplified procedure, with the depleted regions being defined in the shapes similar to those of the concave portions between wirings along the contours of them.

Claims

1. A semiconductor device, comprising:

   a wiring layer comprising a plurality of wirings so as to form concave portions being defined between adjacent ones of the wirings, and an insulating film made of film producing material, wherein the film producing material of said insulating film is adapted to define depleted regions within the concave portions while inhibiting itself from filling the concave portions in the wiring layer.

2. The semiconductor device as defined in claim 1, wherein
   the film producing material of the insulating film comprises fluorinated carbon.

3. The semiconductor device as defined in claim 1, wherein the film producing material of the insulating film comprises coating film.

4. The semiconductor device as defined in claim 1, wherein
   there is given

$$0 \leqq Ha/Hb \times 100 \leqq 6$$

   where Ha is a distance from upper surfaces of the wirings to the highest levels of the depleted regionss, and Hb is a height of the wirings.

5. The semiconductor device as defined in claim 1 or 4, wherein
   there is given

$$0 \leqq Wa/Wb \times 100 \leqq 5$$

   where Wa is the minimum distance between outer side surfaces of the wirings and the depleted regions, and Wb is a width of the concave portions.

6. The semiconductor device as defined in claim 1, wherein
   TiN layer/Ti layer is interposed between the wiring layer and the insulating film.

7. The semiconductor device as defined in claim 6, wherein
   sealing layer comprising an SiN film, an SiO_2 film, or SiC film is interposed between the TiN layer/Ti layer and the wiring layer.

8. A method of manufacturing a semiconductor device, comprising the steps of:

   forming a wiring layer over a substrate, the wiring layer being comprising a plurality of wirings, with concave portions being defined between adjacent ones of the wirings; and
   forming an insulating film of a film producing material on the wiring layer,
   wherein, the step of forming the insulating film including forming the insulating film on the wiring layer while inhibiting the film producing material from filling the concave portions between the adjacent wirings, so as to define depleted regions within the concave portions.

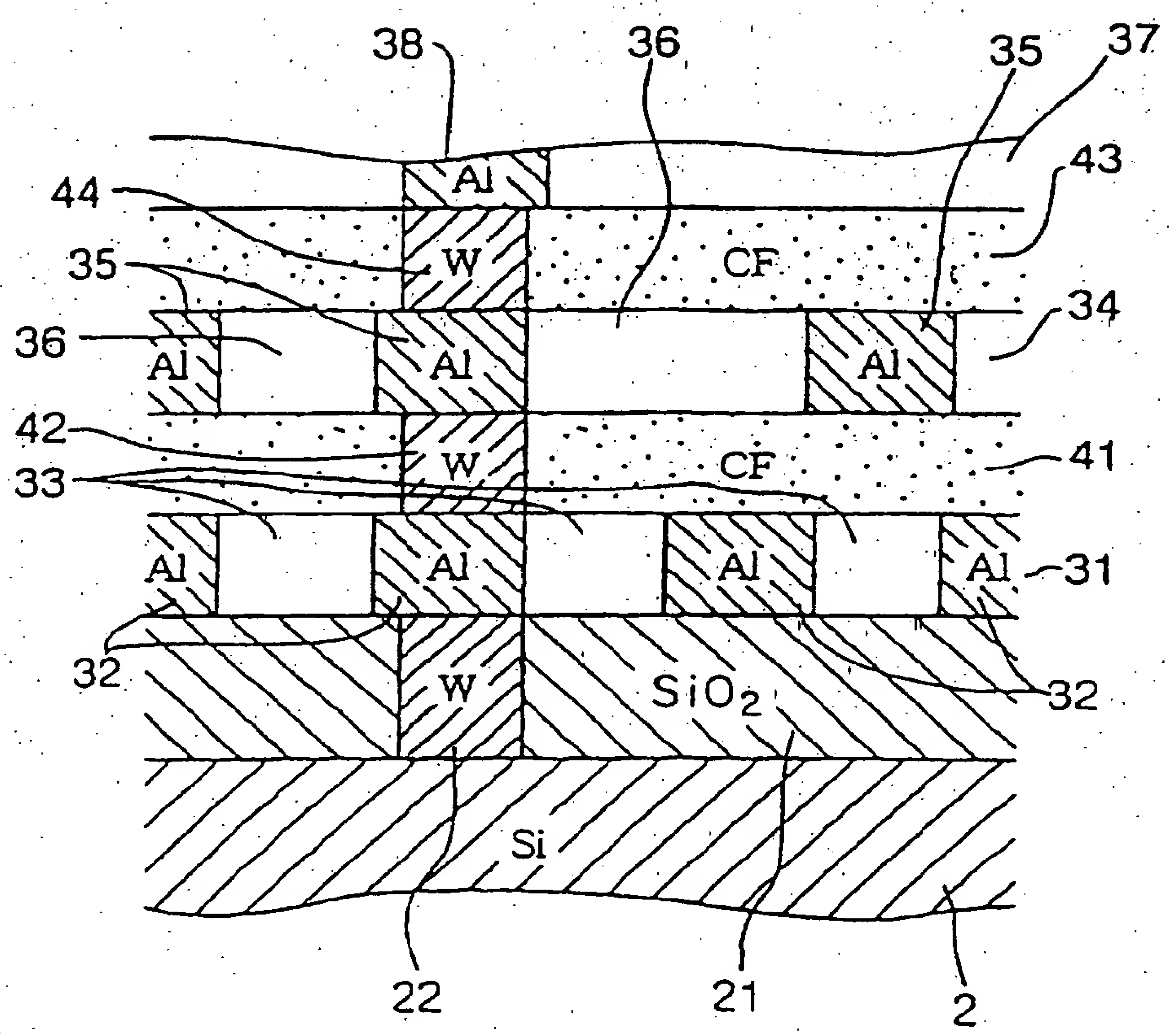
9. The method as defined in claim 8, wherein
   the step of forming the insulating film on the wiring layer includes using fluorinated carbon film which is a compound of carbon and fluorine and which is unlikely to be filling due to its intrinsic property, to serve as the film producing material.

10. The method as defined in claim 9, wherein
    the step of forming the insulating film on the wiring layer includes using fluorinated carbon film which has a benzene ring and is a compound of carbon and fluorine and which is unlikely to be filling due to its intrinsic property, to serve as the film producing material.

11. The method as defined in claim 10, wherein
    the fluorinated carbon film contains hexafluorobenzene.

12. The method as defined in claim 8, wherein
    the step of forming the insulating layer on the wiring layer includes using a coating film to serve as the film producing material.

13. A method as defined in claim 12, wherein
    the step of forming the insulating layer on the wiring layer includes using a SiLK film to serve as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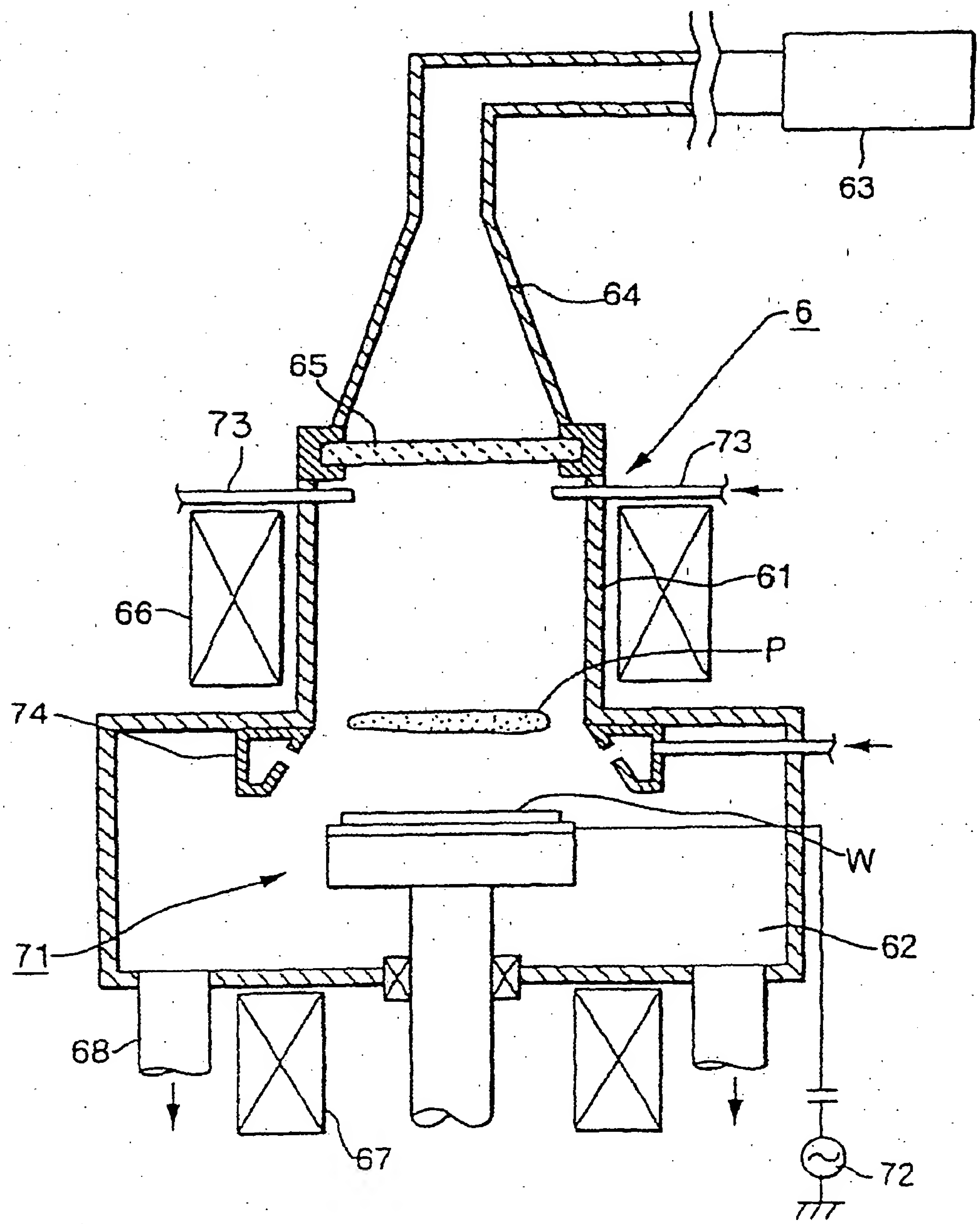
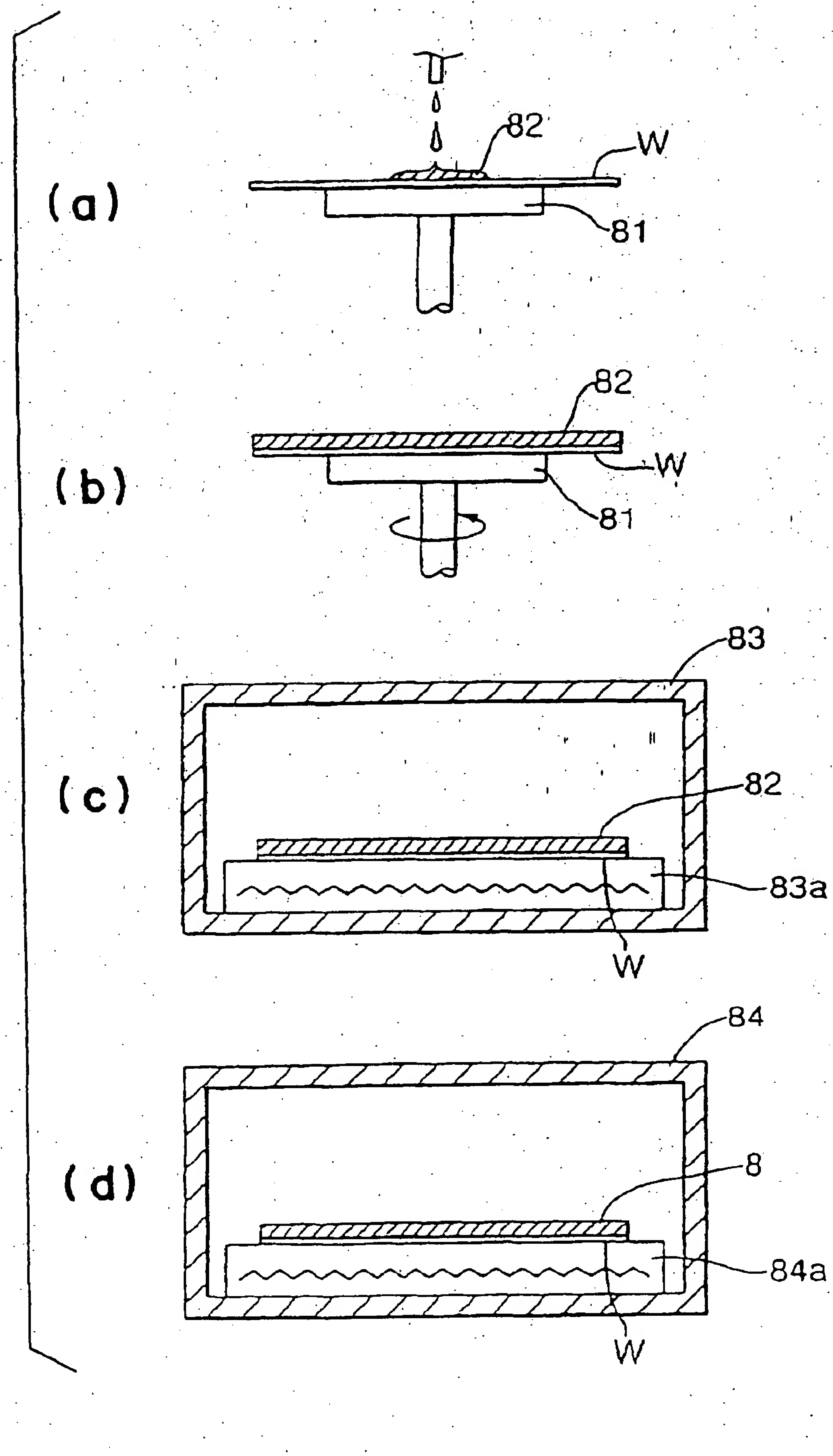
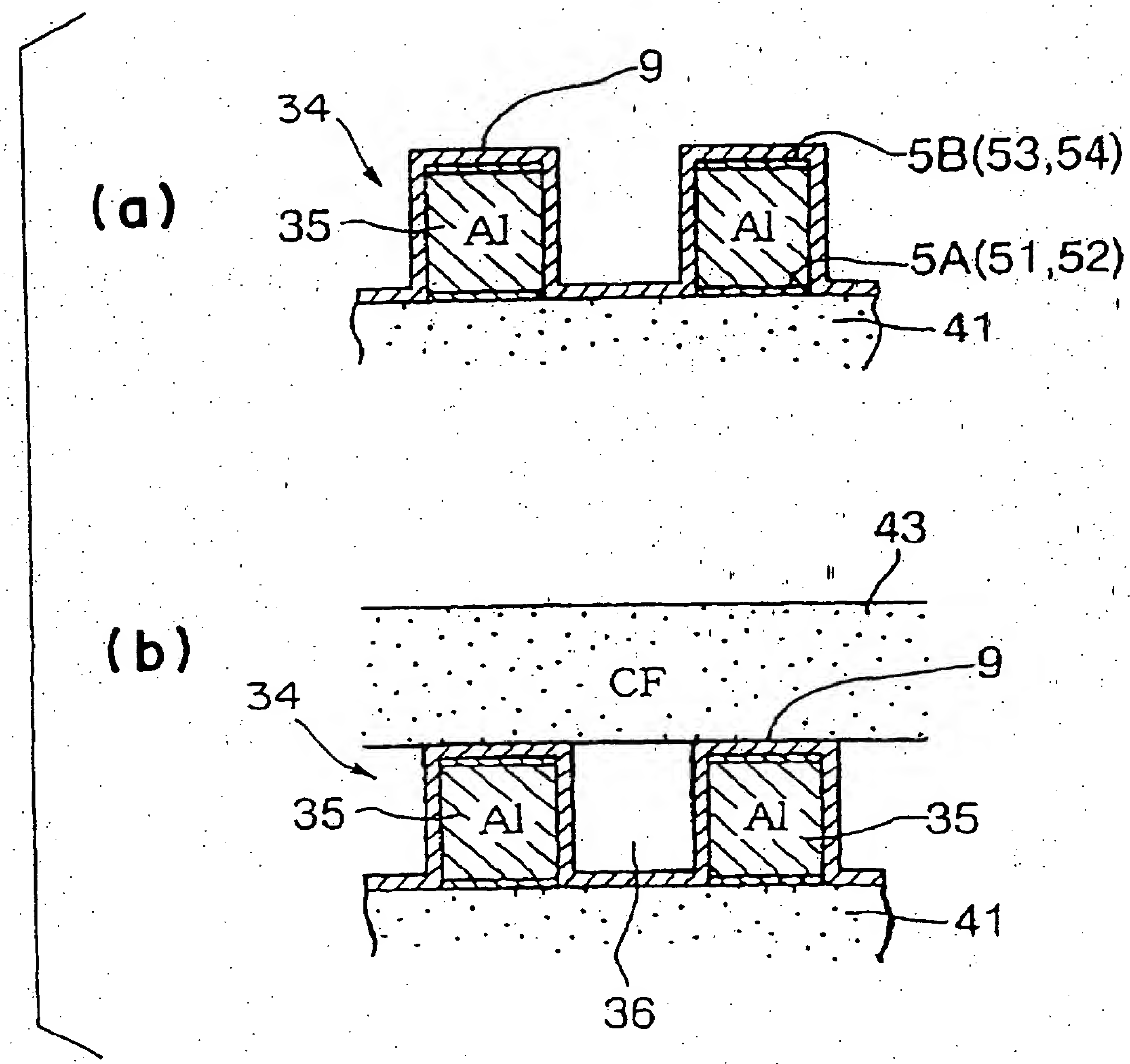


F I G. 3



F I G. 5



F I G. 7

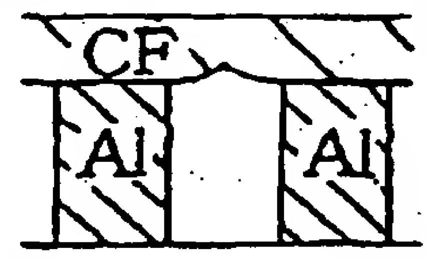
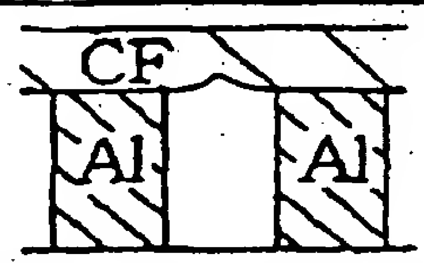
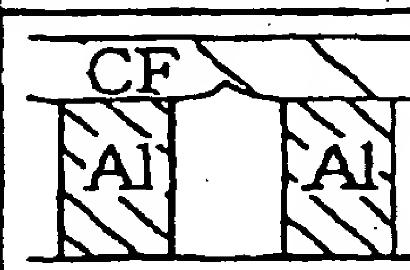
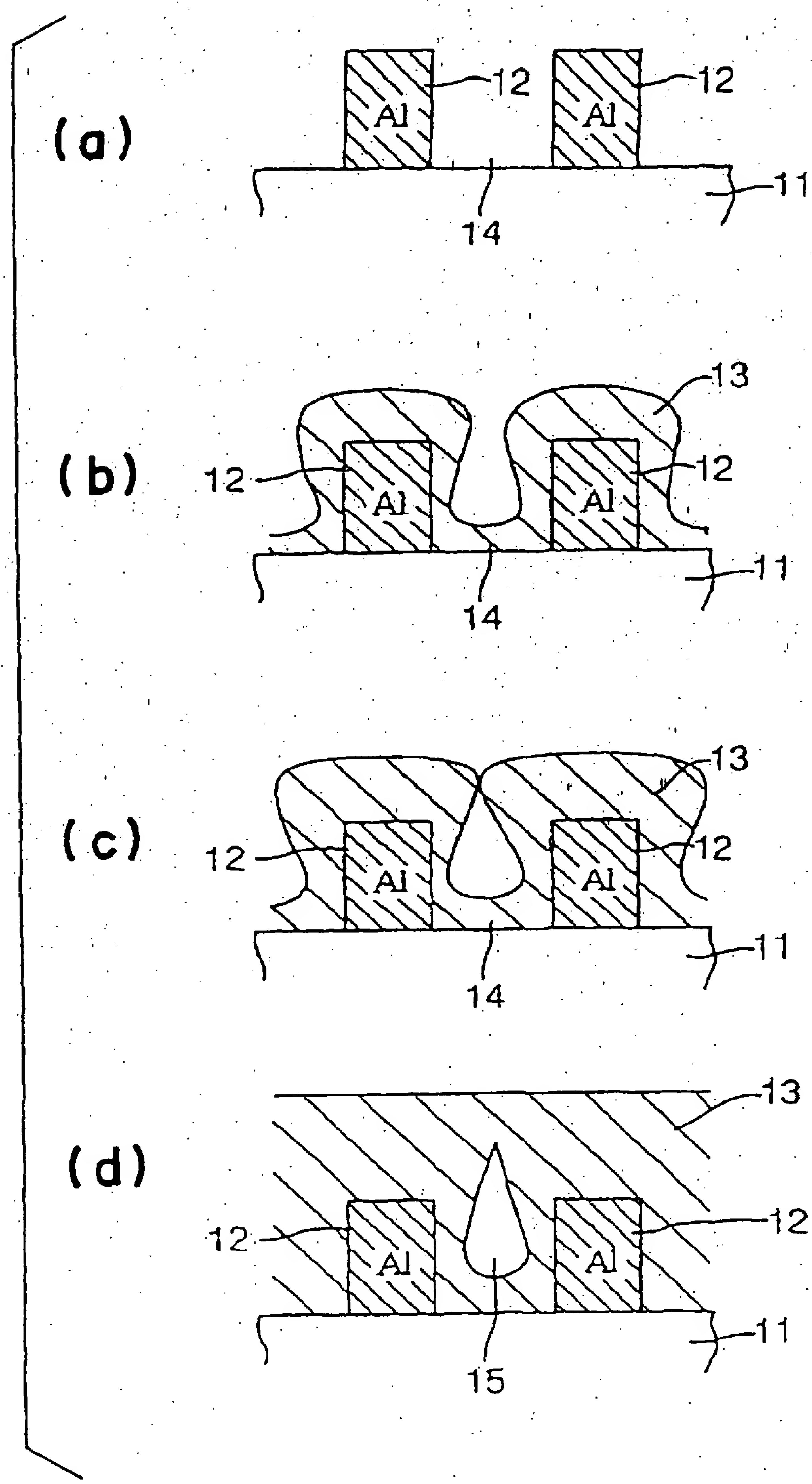
	Ha/Hb×100 (%)	Wa/Wb×100 (%)	AIR GAP SHAPE
EXAMPLE 4	4	1.2	
EXAMPLE 5	6	5	
EXAMPLE 6	3	1.5	
EXAMPLE 7	4	2.7	
COMPARISON 5	25	30	

FIG. 9


(a)
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(c)
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(d)
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FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP00/00079

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl^{7} H01L21/768, H01L21/314

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl^{7} H01L21/768

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1926-1996 Toroku Jitsuyo Shinan Koho 1994-2000
Kokai Jitsuyo Shinan Koho 1971-2000 Jitsuyo Shinan Toroku Koho 1996-2000

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	JP, 10-247648, A (Fujitsu Limited), 14 September, 1998 (14.09.98), Columns 25 to 60 (Family: none)	1,3-5,8,12 2,6,7,10,11,13
X Y	JP, 10-335449, A (NEC Corporation), 18 December, 1998 (18.12.98), Full text (Family: none)	1,8 2-7,8-13
EX	JP, 11-297827, A (NEC Kyushu Ltd.), 29 October, 1999 (29.10.99), Full text (Family: none)	1,3,8,12
EX	JP, 11-312733, A (NKK CORPORATION), 09 November, 1999 (09.11.99), Full text (Family: none)	1,4,8
Y	JP, 8-148556, A (Sony Corporation), 07 June, 1996 (07.06.96), Column 58 (Family: none)	2,9-11

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 March, 2000 (08.03.00)	21 March, 2000 (21.03.00)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)